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LASER BEAM MACHINE AND ITS MACHINING METHOD
[Reezakakouki to sono kakouhouhou]

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SPECIFICATION

[Claims]

[Claim 1] With respect to a laser beam machine that machines a workpiece by irradiating a pulse-like laser beam onto the workpiece inside a vacuum tank,

a laser beam machine characterized by being equipped with

electrodes that are provided in order to generate an electric field in the vicinity of said workpiece,

a power source device that supplies power for electric field generation to said electrodes,

a detecting means that detects the charge quantity of the particles discharged from the workpiece during laser beam irradiation, and

an electric field control means that controls said power source device in accordance with the positive or negative of the charged content of the discharged particles detected by said detecting means and that then generates an alternating electric field in the vicinity of the workpiece.

[Claim 2] A laser beam machine of Claim 1 in which the above-mentioned detecting means detects the above-mentioned charge quantity by detecting the current running in the above-mentioned electrodes.

[Claim 3] A laser beam machine of Claim 1 in which the above-mentioned detecting means detects the above-mentioned charge quantity by detecting the current running in a member for electric charge detection located above the workpiece.

[Claim 4] With respect to a laser beam machining method for machining a workpiece by irradiating a pulse-like laser beam onto a workpiece inside

a vacuum tank,

a laser beam machining method characterized by an electric field being applied to the vicinity of said workpiece, by the charge quantity of the particles discharged from said workpiece as a result of laser beam irradiation being detected, and said electric field being alternated in accordance with the positive or negative of the charge content of said discharged particles.

[Claim 5] A laser beam machining method of Claim 4 in which the charge quantity of the above-mentioned discharged particles is detected based on the current that runs in the electrodes for electric field application.

[Detailed Explanation of the Invention]

[0001] [Field of Industrial Application]

The present invention relates to a laser beam machine and its machining method in which micropores or fine grooves are machined excellently while irradiating a laser beam onto a workpiece inside a vacuum tank and applying an electric field to the vicinity of the workpiece.

[0002] [Related Art]

Laser machining in which a laser beam is irradiated onto a workpiece in order to heat, melt, and vaporize the irradiated portion is being practiced widely.

[0003] However, when machining micropores and fine grooves having an inner diameter of 10m or less are machined by means of laser beam irradiation, the machining residue tends to remain inside the micropores or fine grooves, and there is, therefore, a problem in that thin and deep micropores cannot be drilled with ease.

[0004] For this reason, the present inventors proposed a laser beam machine in Kokai No.6-310473 which discharges the machining residue from the micropores by applying an electric field in the incidence direction of the laser beam, by thus charging the workpiece, and by thus generating a Coulomb force in the machining residue inside the micropores.

[0005] [Problems that the Invention is to Solve]

The above laser beam machine is capable of efficiently discharging the machining residue from the micropores, etc. to some extent, but when machining very thin and deep micropores, etc., the residue discharging becomes difficult to achieve due to a machining limit. For this reason, further research and experiments were carried out. As a result, it was found out that, although the direction of the electric field application must be matched with the direction in which the residue charge was discharged, a phenomenon occurred in which the charge on the irradiation surface appeared to have become inverted during laser beam irradiation.

[0006] In other words, the laser beam machine proposed in the above-mentioned official report generated an electrical field that caused the opposing electrode to be negative with respect to the workpiece in order to draw out the positively-charged ions generated in the workpiece from the machined pores during laser beam irradiation.

[0007] However, the experiments revealed that, when micropores were machined by irradiating a pulse-like laser beam onto the workpiece, negatively-charge electrons were emitted first from the irradiation surface during the laser beam irradiation, and then positively-charged ions were discharged.

[0008] For this reason, when a constant electric field is applied to the vicinity of the workpiece, it becomes difficult for either the negatively-charged electrons or the positively-charged ions to be discharged, and it becomes difficult to discharge the residue from the micropores well. Therefore, there are machining limits to the diameters and depths of the micropores and fine grooves.

[0009] The present invention was completed in light of the above points, and its purpose is to supply a laser beam machine and its machining method capable of efficiently discharging machining residue from micropores and fine grooves and of thus excellently machining even thinner and deeper micropores and fine grooves.

[0010] [Means for Solving the Problems]

In order to achieve the above purpose, with respect to a laser beam machine that machines a workpiece by irradiating a pulse-like laser beam onto the workpiece inside a vacuum tank, a laser beam machine of the invention is characterized by being equipped with electrodes that are provided in order to generate an electric field in the vicinity of the workpiece, a power source device that supplies power to the electrodes for electric field generation, a detecting means that detects the charge quantity of the particles discharged from the workpiece during laser beam irradiation, and an electric field control means that controls said power source device in accordance with the positive or negative of the charged content of the discharged particles detected by the detecting means and that then generates an alternating electric field in the vicinity of the workpiece.

[0011] In this case, the detecting means detects the charge quantity by detecting the current that runs in the electrode or can detect the charge quantity by detecting the current that runs in a charge detecting member located above the workpiece.

[0012] Moreover, with respect to a laser beam machining method for machining a workpiece by irradiating a pulse-like laser beam onto a workpiece inside a vacuum tank, a laser beam machining method of the present invention is characterized by an electric field being applied to the vicinity of the workpiece, by the charge quantity of the particles discharged from the workpiece as a result of laser beam irradiation being detected, and the electric field being alternated in accordance with the positive or negative of the charge content of the discharged particles.

[0013] The charge quantity of the discharged particles can be detected based on the current that runs in the electrode, which is for applying an electric field.

[0014] [Operation and Effects of the Invention]

According to the thus-structured laser beam machine and laser beam machining method, a pulse-like laser beam is irradiated onto a workpiece inside the vacuum tank and generates an electric field in the vicinity of the workpiece at the same time. At this time, the charge quantity of the particles discharged from the workpiece as a result of the laser beam irradiation is detected, and the electric field is generated in a manner such that it becomes alternated depending on the positive or negative of the charged content of the discharged particles.

[0015] In other words, while electrons are being discharged from the workpiece, an electric field is generated in the direction in which the electrons are drawn out from the workpiece, and while positively-charged ions are being discharged, an electric field is generated in the direction in which the positively-charged ions are drawing out.

[0016] Because of this, negatively-charged electrons are first discharged from the workpiece and then positively-charged ions become discharged during laser beam irradiation. These electric fields that are alternately generated in this manner make it possible to draw out the particles of electrons and positively-charged ions, i.e. machining residue, to the outer side and to thus efficiently discharge those particles from the machined micropores and fine grooves. Therefore, even thinner and deeper micropores and fine grooves can be machined at a high efficiency, and pores or grooves having even higher aspect ratios can be achieved.

[0017] [Embodiments of the Invention]

In the following, embodiments of the invention will be explained based on drawings.

[0018] Figure 1 illustrates a schematic structural diagram of a laser beam machine. [1] is a vacuum tank in which machining is carried out. The interior of the tank is connected to a vacuum pump (not shown) and its pressure becomes reduced to a predetermined degree of vacuum. A base electrode [2] and a counter electrode [3] are disposed inside the vacuum tank [1] in order to generate an electric charge in the vicinity of a workpiece, and the workpiece [W] is mounted on the base electrode [2].

[0019] The counter electrode [3] is disposed above the base electrode [2]. The center part of the counter electrode [3] has a hole part [3a] that protrudes toward the workpiece below it, and a laser beam becomes irradiated downward onto the workpiece through the protruding hole part [3a].

[0020] The top part of the vacuum tank [1] is equipped with a light-transmitting window [4], and an objective lens [5] is disposed above the light-transmitting window [4]. The objective lens [5] receives a laser beam irradiated from a laser oscillator [6] through a mirror [7] and focuses it on the workpiece [W]. If the laser oscillator [6] is, for example, an excimer laser device that uses ArF gas, it oscillates and outputs a laser beam having a wavelength of 193nm at an output of 100 ~ 200mJ.

[0021] [10] is a control device for the laser oscillator [6]. It controls the laser oscillator [6] in a manner such that laser pulses of a predetermined width will be oscillated at constant intervals. [11] is a power source device for electric field generation which applies a voltage to a point between the base electrode [2] and the counter electrode [3] in order to generate an electric field in the space between the two electrodes, [2] and [3].

[0022] This power source device [11] for electric field generation comprises a power source part, which supplies power, and a control part, which inverts the electric potential. It applies a voltage that will make the counter electrode [3] positive to a point between the base electrode [2] and the counter electrode [3] to start the generation of an electric field slightly before the irradiation of a laser pulse, switches to a

voltage that will make the counter electrode side negative in synchronization with the timing at which electrons, which were emitted from the workpiece as a result of laser beam irradiation, change into positively-charged ions, i.e. the timing at which the electric charge is converted from negative to positive, and thus applies an alternating electric field.

[0023] In other words, if the workpiece [W] is a conductive body, the workpiece [W] will store the electric charge caused by laser beam irradiation, and electrons will therefore flow into it, which then causes the electric current to flow out. Therefore, a current detector [12] is connected to the power line located between the base electrode [2] and the power source device [11] for electric field generation, and the current flowing out of the base electrode [2] becomes detected. The point in time at which the current from this base electrode [2] becomes zero is the timing at which positively-charged ions start being discharged from the electrons and at which the electric charge changes from negative to positive. At this timing, the electric field becomes inverted.

[0024] Incidentally, if the workpiece [W] is a nonconductor or semiconductor, electrons become discharged toward the counter electrode [3] first in response to the irradiation of a laser beam onto the workpiece [W]. Therefore, a current detector [13] is connected to the power line located between the counter electrode [3] and the power source device [11] for applying an electric field. Based on these electrons, the current running in the counter electrode [3] is detected by the current detector [13]. At the point in time at which the current from the counter electrode

[3] becomes zero is the timing at which positively-charged ions start being discharged from the electrons and at which the electric charge changes from negative to positive. At this timing, the electric field becomes inverted.

[0025] Moreover, as illustrated in Figure 3, it is also permissible to detect the current by means of a current detector [14] by disposing a microchannel plate [8] and its electrode [9] above the counter electrode as members for detecting electric fields, by connecting the current detector [14] to this microchannel plate [8], by connecting a high-voltage power source, which is used for microchannel plates, to the electrode [9], and by amplifying the charge of the electrons or ions discharged from the workpiece [W].

[0026] Next, the operation of a laser beam machine having the above structure will be explained.

[0027] The laser oscillator [6] oscillates in response to trigger signals output from the control device [10] and outputs pulse laser beams of a predetermined width at constant time intervals as indicated in Figure 2. At this time, the power source device [11] for electric field generation starts applying a positive voltage (an electric potential high on the counter electrode side) to a point between the counter electrode [3] and the base electrode [2] shortly before a pulse laser beam is output, and thus generates a positive electric field in the space between the two electrodes, that is to say in the vicinity of the workpiece.

[0028] After a pulse-like laser beam is focused through the mirror [7] and the objective lens [5] and is then irradiated onto the workpiece

[W], the workpiece [W], if it is a conductive body, stores the electric charge in response to the irradiation of the laser beam. Therefore, electrons flow into it, which causes the current to run in the direction of the workpiece and the base electrode [2]. Therefore, the current becomes detected by the current detector [12] located between the base electrode [2] and the power source device [11] for electric field generation.

[0029] Incidentally, if the workpiece [W] is a nonconductor or semiconductor, electrons become discharged toward the counter electrode [3] in response to the irradiation of a laser beam. Therefore, the current becomes detected by the current detector [13], which is connected to the power line located between the counter electrode [3] and the power source device [11] for applying an electric field, or by the current detector [14], which is connected to a microchannel plate [8] such as that of Figure 3.

[0030] Moreover, the discharging of electrons from the workpiece [W] is soon replaced by the discharging of positively-charged ions. The timing at which this switching from electrons to positively-charged ions occurs is detected in relation to the timing at which the current detected by the current detector [12] becomes zero. As indicated in Figure 2, at this timing, the power source device [11] for electric field generation reverses the electric field. In other words, it reverses the electric field by making the electric potential of the counter electrode [3] to be negative with respect to the base electrode [2]. The generation of this negative electric field is maintained until shortly before the timing at which the next laser pulse is irradiated.

[0031] Thus, an electric field that is positive on the counter electrode side is generated while electrons are discharged from the workpiece at the start timing of pulse laser beam irradiation. Therefore, negatively-charged electrons can be drawn out from the workpiece [W] efficiently. After that, an electric field that is negative on the counter electrode side is generated while the positively-charged ions are discharged from the workpiece [W], and therefore, positively-charged ions can be drawn out from the workpiece [W] efficiently.

[0032] Therefore, even during the machining of micropores or fine grooves, the machining residue can be discharged from the pores or grooves efficiently, which makes it possible to efficiently machine micropores and fine grooves. Moreover, it is possible to machine micropores, etc. that have even higher aspect ratios, in other words, micropores, etc. that are even thinner and deeper.

[0033] In addition, it is thought that the time (a very short time) it takes for the electrons discharged from the workpiece [W] to reach the counter electrode [3] or microchannel plate [8] will slightly delay the electric-field reversing timing, but it is possible to compensate for this delay by means of a calculation in which it is taken into consideration with respect to the timing at which the peak generation of the detected current (peak generation of a negative charge), etc. is detected.

[Brief Explanation of the Drawings]

[Figure 1] A schematic structural diagram of a laser beam machine of one embodiment of the invention.

[Figure 2] Timing charts that indicate the change in the quantity of the electric charge discharged from the workpiece, the change in the intensity of the laser beam, and the change in the electric potential of the counter electrode.

[Figure 3] A cross-sectional drawing of the essential part of the laser beam machine of another embodiment.

[Explanation of the Reference Numerals]

[1] = vacuum tank

[2] = base electrode

[3] = counter electrode

[6] = laser oscillator

[10] = control device

[11] = power source device for generating electric field

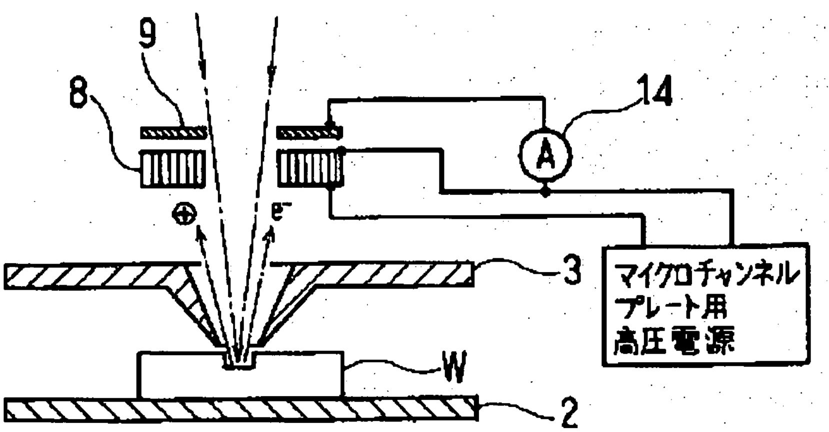
[12],[13],[14] = current detector

[W] = workpiece

[Figure 1]

Key: 11)power source device for electric field generation; 10)control device.

[Figure 3]



Key: a)high-voltage power source for microchannel plate.

[Figure 2]

Key: a)quantity of discharged electric charge; b)laser intensity; c)potential of counter electrode; d)time; e)Part corresponding to the positively-charged ions discharged from the workpiece.; f)Part corresponding to the electrons discharged from the workpiece.